REMOTE SENSING CENTRE

LAND COVER MAPPING FROM LANDSAT TO AID IN HYDROLOGIC BUDGET EVALUATION ON THE ASSINIBOINE DELTA AQUIFER

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A COOPERATIVE PROJECT UNDER THE TECHNOLOGY ENHANCEMENT PROGRAM BETWEEN THE MANITOBA REMOTE SENSING CENTRE, MANITOBA WATER RESOURCES BRANCH AND CANADA CENTRE FOR REMOTE SENSING

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ABSTRACT

Under the terms of the Technology Enhancement Program, the Manitoba Remote Sensing Centre and the Canada Centre for Remote Sensing conducted a cooperative land cover mapping project with the Manitoba Water Resources Branch. The purpose of the project was to demonstrate the use of remote sensing techniques for water resources management and to provide Branch staff with an opportunity to learn about recent developments in remote sensing. The specific objectives were to map recent (i.e. 1983) land cover on the Assiniboine Delta Aquifer and to estimate the area of each cover type.

All four MSS bands from an August 8, 1983 image plus a 5/7 ratio, a $^{(7-5)}/(7+5)$ vegetation index and a principal component were used as input into the supervised classification. With ground reference data gathered by Water Resources staff, ten major land cover types over an area of 258,273 hectares were mapped. Thematic maps at scale 1:125,000 were produced and registered to a topographic base map with a mean standard error of less than one pixel.

A comparison of check training areas generated for each cover type using ground reference data, with computer classified results for a sample area of 74,235 pixels revealed that 64,436 pixels or 87 percent had been correctly classified. Of the 9799 pixels incorrectly classified 40 percent had been left unclassified. Unclassified pixels were the result of either cloud cover or due to reduced signature files intentionally created by the training area purification process. Many of these errors were corrected using the manual theme generation process or by a minimum area post-classification filter.

A major discrepancy in classification between cereals and mixed grassland/shrub became evident. Examination of air photo mosaics and soils maps showed that the area of confusion was only evident on the Stocton Loamy Sands. A theme bit exchange routine developed specifically to resolve this problem proved to be successful.

The management of both surface and ground water resources in the Province of Manitoba is conducted at both the local and regional level.

Landsat derived information is best suited to regional applications, therefore it should be considered as a tool to assist in overall water resources management.

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1. INTRODUCTION

1.1 Background

The Manitoba Remote Sensing Centre (MRSC) in cooperation with the Manitoba Department of Natural Resources, Water Resources Branch and the Canada Centre for Remote Sensing (CCRS) conducted a land cover mapping project on the Assiniboine Delta Aquifer. The study was one in a series of demonstration projects conducted under a joint Federal/Provincial Technology Enhancement Program (TEP). The objective of TEP was to enhance the scientific and technical capabilities of remote sensing technology to resource management activities in Manitoba.

The purpose of this report is to document the techniques and results of the land cover mapping project. The results of this study are but one input into the Water Resources Branch attempt to determine the overall hydrologic budget of the Assiniboine Delta Aquifer.

1.2 Resource Issue

The Assiniboine Delta Aquifer has recently experienced increased land development for agricultural production. Some areas that were pseudo semi-arid due to high soil permeability and therefore unsuitable for crop production, have over the past seven years become productive through irrigation schemes that utilize ground water. Land owners in the area rely on the groundwater to satisfy their domestic and livestock needs. The Water Resources Branch is attempting to calculate the aquifer's overall water budget and to determine the effect of sustained irrigation activities on the non-irragated farmland and surrounding natural areas. Reliable information on land cover is required as one input into the water budget model for the entire aquifer.

1.3 Objectives

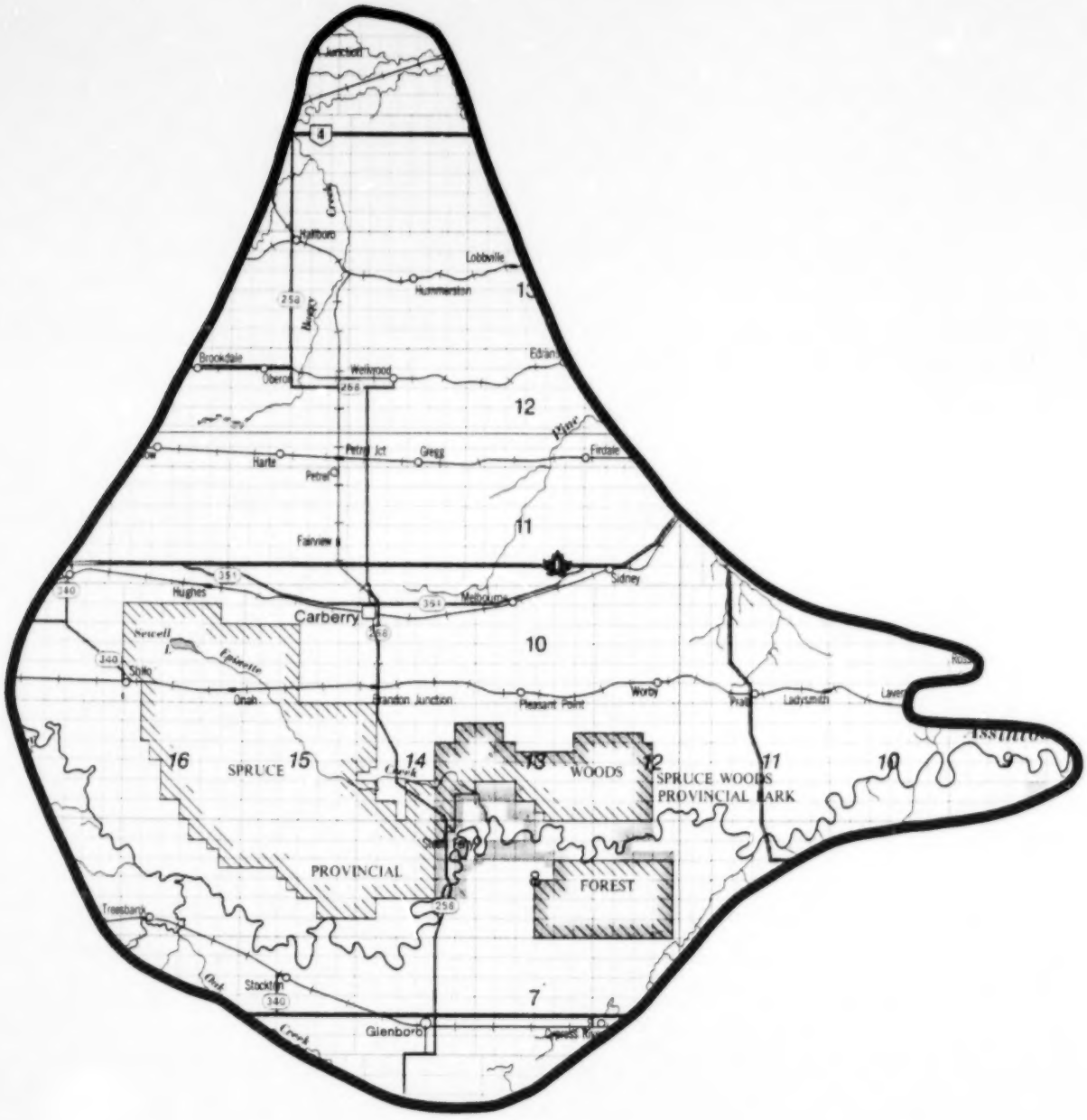
The purpose of this study was to determine the operational feasibility of using remote sensing techniques to assist in water resources management. The specific objective of the study was to map land cover on the aquifer for 1983 and to provide area estimates for each cover type to be used for making quantitative estimates of water usage.

Of equal importance to the specific objective, was participation in this project by staff at the Water Resources Branch. This would enable them to obtain a first-hand opportunity to learn more about recent developments in remote sensing.

1.4 Study Area

The study area was located approximately 150 kilometres west of Winnipeg (Figure 1). The area was bounded on the east by the Manitoba Escarpment which varies in form from a sharp bank deeply incised by ravines to a gently sloped terrace (Ehrlich et al 1957). To the south, the Assiniboine River occupies a broad U-shaped valley of as much as 200 feet in depth. The Assiniboine Delta is an area of glacial deltaic deposits and lacustrine plains which have been dissected by river channels and glacial spillways. The sandy deltaic deposits have been modified by wind and large sand dunes occupy most of this area. The medium and fine textured deposits in the central portion of the delta have smooth level topography. These deposits are underlain at shallow depths by thick beds of stratified sands.

The Assiniboine Delta Aquifer lies at the southern edge of the Mixedwood region as delineated by Rowe (1972). The characteristic forest association is dominated by trembling aspen (Populus tremuloides) but also includes balsam poplar (Populus balsamifera), white birch (Betula papyrifera), white spruce (Picea glauca), balsam fir (Abies balsamea) and bur oak (Quercus macrocarpa). There are also minor occurrences of white elm (Ulmus Americana), green ash (Fraxinus pennsylvanica), Manitoba maple (Acer negundo) and on the dry till soils, jack pine (Pinus banksiana).



ASSINIBOINE DELTA AQUIFER

Figure 1: Study area.

The rolling plains on the western portion of the delta are dominated by mixed prairie grasses including big and little bluestem (Andropagon spp.), prairie cordgrass (Spartina pectinata), rough fescue (Festuca spp), wheat grasses (Agropyron spp.), bluegrasses (Poa spp.) and timothy (Phleum pratense). Areas north and east of the sand dunes are covered by scattered stands of mixed woods interspersed by prairie vegetation. The lacustrine plain bordering the Manitoba Escarpment is thickly wooded.

1.5 Cover Type Classification

The hierarchical classification system adopted for this project consisted of five, level I categories which are general in nature and ten, level II categories which are more specific (Table 1). The following is a description of each cover type:

I AGRICULTURAL CROPS - This category consisted of three specific crop types and one conglomerate of several similar crop types. The specific crops identified were canola/rapeseed, potatoes and corn. The conglomerate consisted of wheats, oats, barley, flax, rye and oats.

II EXPOSED SOILS - This category consisted of summerfallow, roads, sand dunes and blowouts.

III WOODLAND - Included in this category were all lands dominated by deciduous and coniferous tree cover. Two specific categories of Woodland were identified including coniferous and mixedwood. The mixedwood cover type consisted primarily of deciduous tree cover but also included scattered spruce and fir species.

IV GRASSLAND - Two categories of Grassland were identified including mixed grassland/shrub and mixed grassland/pasture. The mixed grassland/shrub cover type was dominated by mixed prairie grasses and herbs but also included small

TABLE 1

COVER TYPE CLASSIFICATION SYSTEM USED TO DESCRIBE LAND COVER ON THE ASSINIBOINE DELTA AQUIFER.

	LEVEL I DESCRIPTION	LEVEL II DESCRIPTION
I	AGRICULTURE	a) canola/rapeseed
		b) corn
		c) potatoes
		d) cereals
II	EXPOSED SOILS	a) summerfallow, roads and sanddunes.
III	WOODLAND	a) Woodland/conifer
		b) Woodland/mixed
IV	GRASSLAND	a) mixed grassland/scrub
		b) natural grassland/pasture
V	WATER	a) rivers, lakes, ponds

scattered stands of scrubby aspen-oak woods and associated shrubs such as willow (Salix spp.), chokecherry (Prunus virginiana), saskatoon (Amelanchier alnifolia) and pincherry (Prunus pensylvanica). The mixed grassland/pasture cover type was again dominated by mixed prairie grasses but also included improved pastures and tame forage.

V WATER - This category included all lakes, rivers, and ponds of open water.

2. METHODS

2.1 Data Acquisition

Aerial photographs of the study area archived at the Manitoba Air Photo Library (MAPL) were examined to determine the extent of their coverage, scale, type and dates. Complete coverage at scale 1:15,840 with black and white photos were available for the year of 1980. In addition, a complete set of photo mosaics at the township level were available.

Landsat microfiche were examined to determine the availability of satellite data for the area. Selection criteria included a cloud free image taken some time in the period between early July and late August. The following Computer Compatible Tapes (CCT) from track 32, frame 25 with a 9.5 second off-set were selected:

IMAGE DATE	CLOUD COVER
August 8, 1983	8%
June 10, 1982	0%
August 3, 1982	0%

The scenes ordered for the spring and summer of 1982 were intended for use in multitemporal analysis. Line start problems with the 1982 data resulted in poor image registration to 1983 data and detailed ground reference data for 1982 was not available. Therefore little time was spent doing multitemporal analysis.

Detailed ground reference for the study area was gathered by the Water Resources Branch. Crops and other cover types noted from a vehicle while driving roads in the area were accurately recorded onto 1:125,000 topographic maps. This data was used to train the computer on specific cover types, to generate manual theme files for misclassified areas and to assess classification accuracies. The ground reference data is available from the Manitoba Water Resources Branch.

2.2 Image Analysis

Computer analysis of satellite data was performed with the Applied Resource Information Exploitation System (ARIES-II) image analysis system using version 2.1 of the AIIASP software. Image analysis operations were conducted in three phases with the general sequence of operations shown in Figure 2. Phase one consisted of image preprocessing including geometric corrections and creation of vegetation indices. Phase two processing resulted in production of a classified image. The third phase consisted of post classification filtering, manual theme assignments, area calculations, accuracy assessments and generation of output products. The following is a detailed discussion of each phase.

2.2.1 Preprocessing

Image preprocessing operations consisted of image to Universal Transverse Mercator (UTM) grid registration and image to image registration. The first step in the image to grid registration was to generate a series of ground control points (GCP). GCP's are well-defined points such as road crossings that can be identified by their coordinates on both the satellite image and the UTM grid. Fifteen GCP's identified by their line/pixel coordinates on the satellite image were linked to northing/easting coordinates on the UTM grid system. The image transformation or change in image geometry was conducted via the resampler task using a first order transformation (Shlien 1979).

Similar principals of linkage and image transformation were followed when conducting image to image registration. Common points on both images were identified; however, due to line start problems with the 1982 data it was difficult to generate an acceptable polynomial transform file.

The next stage in the image preprocessing phase was to generate a number of vegetation indices (VI) which would be used as additional feature files to provide greater spectral divergence between cover types. Vegetation indices were generated under the normalization (NO) program.

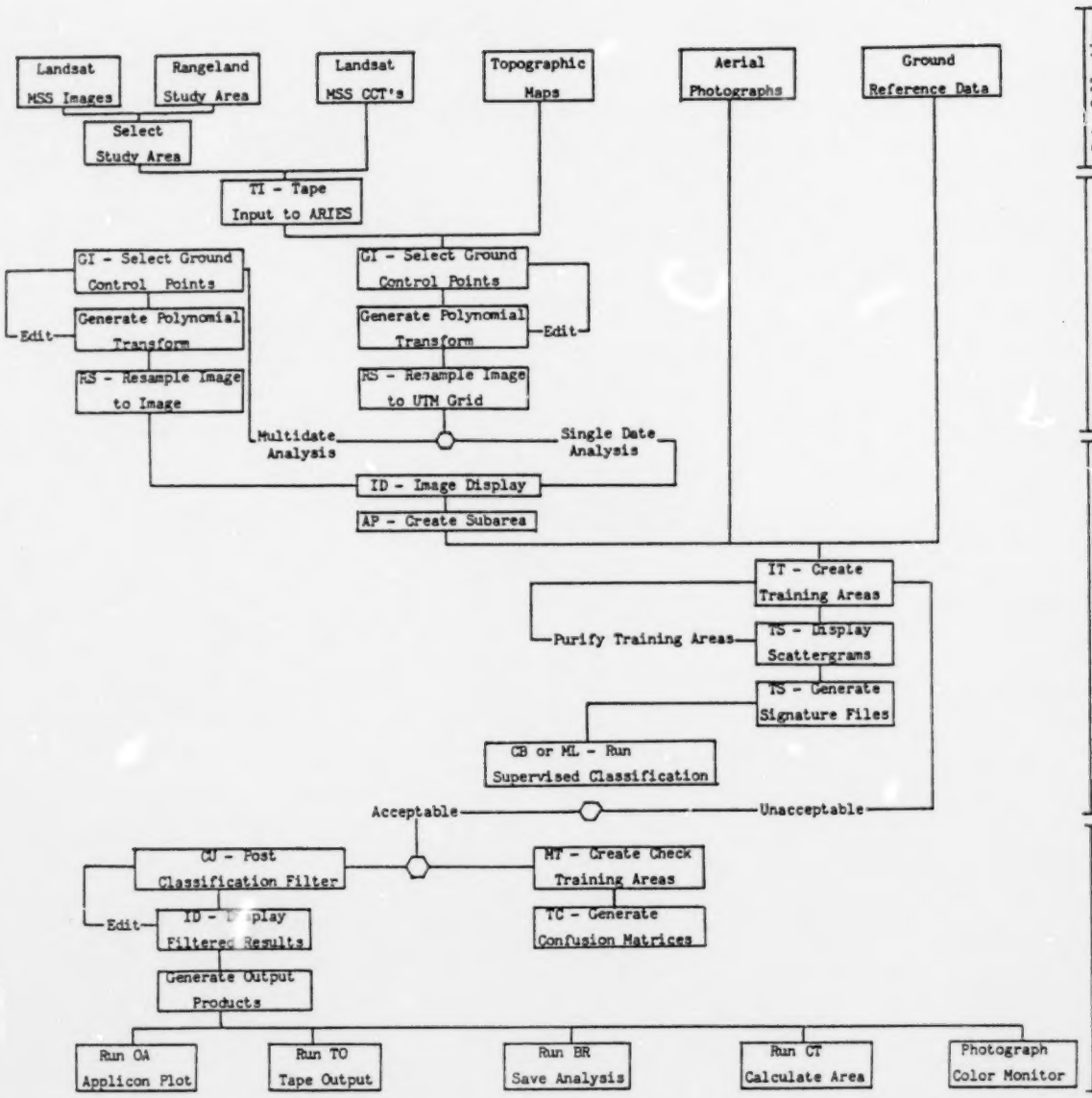


Figure 2. Flow chart of image analysis procedures followed on the ARIES system.

The first vegetation index was a simple ratio of MSS5/MSS7 and is termed the Ratio Vegetation Index (RVI) or Biomass Index. The second vegetation index was derived by (MSS7-MSS5)/(MSS7+MSS5). These ratios are described by Yazdani et al (1981) and Richardson and Wiegand (1977).

In addition to the vegetation indices, a Karhumen-Loeve (principal component) transform was generated as another feature file (Kourtz and Scott 1978). The K-L transform was used to rotate the axes of image space into alignment with the axes of a hyperellipsoid defined by the signature of a specified training area. A combined grassland and cereals signature was used to define the K-L transform in anticipation that this would enhance these specific classes. The first component was selected for use as a feature file.

2.2.2 Classification

The objective of this phase was to produce a classified image using ground reference data to train the computer to recognize cover types of interest. Training was the process of defining areas on the satellite image that contained pixels known to be representative of a specific cover type. For this reason it was imperative that ground reference data show not only areas with known cover types but also their exact geographic location.

Because every pixel within a training area relayed significant spectral information about the cover type to the computer it was important to be selective and exact when choosing and defining training areas. Several training areas for the same cover type were selected from different locations on the image. In doing so, slight differences in spectral reflectance due to site-specific conditions were accounted for in the training set. A training set was comprised of all training areas created for the same cover type.

Although training areas were carefully selected it was still possible that they could contain pixels whose reflectance values were not truely representative of the specific cover type. For example, border pixels included in the training area could possess a spectral signature that differed from the "true" signature because of the influence that neighboring cover

types had on the pixel's total reflectance. To detect the presence of these non-conforming pixels a scattergram of reflectance values for a vegetation index versus a principal component was examined. A composite scattergram showing clusters for all training sets is shown in Figure 3.

The scattergram is a standard X-Y plot representing two-dimensional vector space. The pattern and location of each cluster are important for locating non-conforming pixels and for understanding where confusion between cover types might be expected to occur. Confusion can be expected whenever two spectral clusters meet or overlap. By reducing the number of nonconforming pixels and the amount of overlap, confusion between cover types can be reduced at the expense of leaving more of the image unclassified. This procedure is called training area purification.

Training area purification was a process whereby a maximum likelihood thresholding function was applied to all pixels in a training set. Only those pixels which fell within an operator defined percentage of the mean were retained to be used later for signature generation. After each purification run, the scattergram with the reduced data set was viewed and if necessary the purification process was conducted again until the number of nonconforming pixels and overlap between spectral clusters was reduced. It is important to note that the scattergram represents only two feature files and that the actual signatures for each cover type were generated from a total of seven feature files. Therefore two clusters that appeared to overlay in two dimensional vector space may in fact be better isolated in seven dimensional vector space.

When all training areas had been purified to a satisfactory degree, a spectral signature for each training set was generated under program TS. These signatures were then used as input into the maximum likelihood classifier running under program ML. The classification was performed using ten signature files and a 7-feature data set was comprised of bands 4, 5, 6 and 7, a vegetation index, a biomass ratio and a principal component.

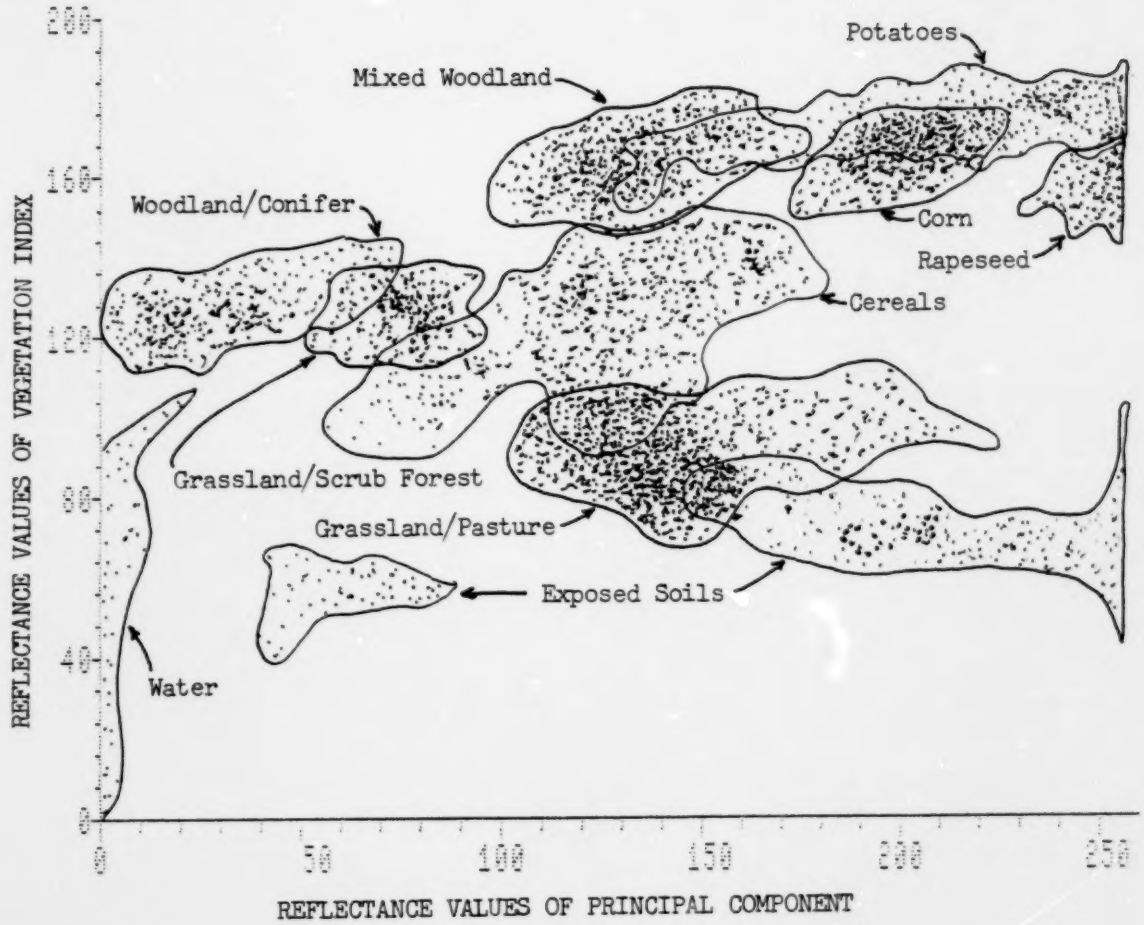


Figure 3. Scattergram showing the pattern and location of spectral clusters associated with each training set. Axes indicate values of a vegetation index versus the first component from principal component analysis.

2.2.3 Post Classification Analysis

Post classification analysis included application of a minimum area filter, accuracy assessment, manual theme generation, area calculations and generation of applicon plots.

The custerer or minimum area filter running under program CU was used to reduce the "salt and pepper" effect of thematic maps by allowing replacement of small areas with larger surrounding areas. The filtering parameters assigned to the classified image for this project were as follows:

STEP ONE - MAP FILE GENERATION

1. Diagonally connected pixels were not considered to be in the same area.
2. Smallest undefined area was 10 pixels.

STEP TWO - REPLACE MINIMUM AREAS

1. Maximum eat-in depth was 3 pixels.
2. Different minimum areas assigned to each theme were as follows:

THEME NUMBER	COVER TYPE DESCRIPTION	AREA (PIXELS) MINIMUM
1	Rapeseed/Canola	3
2	Mixed Grassland/Scrub	3
3	Water	2
4	Grassland/Pasture	4
5	Woodland/Conifer	2
6	Corn	4
7	Cereals	8
8	Exposed Soils	3
9	Woodland/Mixed	4
10	Potatoes	3

3. Unclassified pixels were treated as a theme and assigned a minimum area of 9.

The minimum size areas selected for the filter were based on a visual comparison between classification results and ground reference data. Several combinations of minimum size areas were tried; however, these parameters were found to yield the most satisfactory results.

After the filtered image had been produced, the results were compared with check training areas and a confusion matrix was generated. Check training areas were located with the aid of ground reference data. Each check training area represented a known cover type and was assigned to a separate theme file but in the same theme bit position as the original classification. A theme compare (TC) program was used to compare manually generated themes with the classifier theme.

The confusion matrix generated by TC provides an indication of cover type classification accuracy and also indicates where potential problems of confusion between cover types may exist. It was during this step in post classification analysis that we learned of a major confusion between cereals and mixed grassland/scrub.

Examination of air photo mosaics showed that the confusion between these two categores was limited to the sand dune areas associated with course textured deposits of Stockton Loamy Sand. While other cover types did not appear to be affected, it was noted that large areas of mixed grassland/scrub were consistantly classified as cereals. In order to rectify this problem of misclassification, a theme bit exchange routine was developed.

The theme bit exchange routine as described in Appendix I, was a 12 step process beginning with the creation of a training area that outlined the area where misclassification occurred. This training area was delineated using air photo mosaics and soil survey maps as a guide. Upon completion of the process, theme bit position 7 (cereals) had been replaced by theme bit position 2 (mixed grassland/scrub) within the large training area. The process had essentially swapped theme bit positions in this specific area, without affecting other theme bit positions either inside or outside the training area.

The manual theme generation program was used to delineate the Assiniboine River and to correct other misclassifications that were detected with the aid of ground reference data. When all filtering and manual theme adjustments had been made area calculations for each cover type were

generated.

The final task in the post classification phase was to produce an applicon plot of the thematic classification. Township lines and major roads were then drawn onto the plots and each map was covered with a clear, high-gloss plastic coating to protect them from smudging and fading. A copy of the thematic map may be viewed at either the Manitoba Remote Sensing Centre or the Manitoba Water Resources Branch.

3. RESULTS AND DISCUSSION

3.1 Preprocessing

Acquisition of uncorrected CCT's from Prince Albert Satellite Station (PASS) and subsequent geometric corrections applied in-house on the ARIES-II system was an efficient means for obtaining geometrically corrected satellite data provided that computer time was available. The resampler task (RS) required extensive batch processing time and required complete access to the video display subsystem; however, this job could be run during non prime-time hours. On average, 4.0 hours per band were required to resample 50 m x 79 m pixels to 50 m x 50 m pixels. Including the 6.0 hours required to select GCP's, the total computer time needed to correct the image was 22.0 hours.

Another advantage of conducting in-house geometric corrections on CCT's is that the entire study area may be extracted from the full scene and stored as one set of feature files. Had DICS products been utilized (ie. tapes with geometric corrections already applied) then two tapes and subsequently two sets of feature files would have to be moved through image analysis procedures. While this would not likely increase batch processing time requirements it would mean twice the amount of operator interaction time. DICS products are more suited to smaller area studies.

The accuracy of geometric corrections depend on the care taken in selecting ground control points and the order of the polynomial transform applied (Shlien 1979). Selection of 15 GCP's and a first order transformation resulted in a mean standard error in the pixel direction of 0.67 pixels and in the line direction of 0.42 pixels. The magnitude of error was subpixel and could be seen as a slight shift of less than one pixel in either direction across the entire study area. In otherwords, when the geometrically corrected image was overlaid onto a topographic map, the fit was within one pixel.

3.2 Accuracy Assessment of Classification

The ability to correctly classify and accurately locate ground features of interest is a fundamental concern to Landsat users. An assess-

ment of mapping accuracy was made by comparing known ground cover types with computer classified results (Figure 4). Van Genderen and Lock (1977) pointed out that from this matrix not only could the percent of all land correctly classified be estimated but also the percentage of land correctly classified by each cover type.

The matrix is read by selecting a cover type from the ground reference data column and moving across the table to the corresponding cover type in the supervised classification row. For example, in the corn category 8,435 pixels out of a total 8,734 were correctly classified as corn (Figure 4). The remaining 299 pixels were incorrectly classified as other cover types.

The following section outlines major differences noted between manual and classifier theme files for each individual class. In the rapeseed category 93 percent were correctly classified and the major discrepancy was noted in the unclassified pixel category. After closer examination of this confusion it was noted that several known rapeseed fields had been left unclassified due to effects of clouds or shadows. Classification of other rapeseed fields looked very good, therefore in cloud affected areas the known rapeseed fields were drawn on manually.

In the mixed grassland/scrub forest category only 75 percent of the 8666 pixels sampled were correctly classified. The greatest confusion occurred with cereals and unclassified areas. A further problem was areas known to be mixed grassland/scrub forest but which had been left unclassified as the result of cloud cover. This problem was corrected using manual theme generation. The confusion with cereals was a more serious problem and after closer examination it was noted that nearly all of the mixed grassland/scrub forest category located on the Stockton Loamy Sands had been classified as cereals. This problem was corrected using the theme bit exchange routine outlined in Appendix 1.

In the water category 94 percent of the pixels were correctly classified. The remaining 144 incorrectly classified pixels were distributed among the other classes. Nearly half of these pixels fell into the unclassified category and again the problem was related to cloud cover. Other incorrectly classified pixels were most often associated with lake or river shorelines.

The grassland/pasture category was correctly classified 93

MANUAL THEME FILES	CLASSIFIER THEME FILES: Rapeseed	Mixed Grassland/Scrub	Water	Grassland/Pasture	Woodland/Conifer	Corn	Cereals	Exposed Soils	Woodland/Mixed	Potatoes	Unclassified	Number Correct	Number Incorrect	Total	% Correct
Rapeseed	10778	0	0	8	0	140	73	2	3	131	395	10778	752	11530	93%
Mixed Grassland/Scrub	1	6564	89	189	36	48	874	43	290	13	519	6564	2102	8666	75%
Water	0	7	2501	17	1	22	7	14	0	6	70	2501	144	2645	94%
Grassland/Pasture	27	239	44	14085	28	82	463	83	31	20	19	14085	1036	15121	93%
Woodland Conifer	0	75	0	0	513	0	5	0	8	0	62	513	150	663	77%
Corn	21	0	0	8	0	7958	181	29	135	257	163	7958	794	8752	90%
Cereals	0	441	0	423	0	46	8222	8	177	3	1569	8222	2667	10889	75%
Exposed Soils	0	3	0	162	0	0	5	1005	1	0	409	1005	580	1585	63%
Woodland Mixed	0	286	0	0	0	25	17	0	7732	22	568	7732	918	8650	89%
Potatoes	33	3	0	1	2	332	38	1	62	5078	184	5078	656	5734	88%
Total											3958	64436	9799	74235	87%

FIGURE 4. Confusion matrix of manually classified pixels in check training areas versus pixels in the classifier theme files.

percent of the time. Most errors were made with the cereals and mixed grassland/scrub forest categories. This kind of error can be expected because of the similarity between these cover types.

Of the 663 known woodland/conifer pixels, 513 or 77 percent were correctly classified and the highest number of incorrectly classified pixels were found in the unclassified pixel category. These unclassified pixels were difficult to explain but after closer examination it was felt that better classification results could have been achieved had the signature for this category been expanded slightly. However, given the relatively small amount of conifer cover type on the study area, it was deemed unnecessary to run the classification process again.

In the corn category 90 percent of the 8752 corn pixels were correctly classified. Of the 794 pixels incorrectly classified 257 pixels or 32 percent were classified as potatoes and 181 pixels were classified as cereals. It was noted that in many of the non-irrigated corn fields used as check training areas that there were often several border pixels that were classified as either cereals or potatoes. In otherwords, seldom was an entire corn field missed altogether. The problem of border pixels being misclassified on the irrigated corn fields was less apparent. The majority of unclassified pixels in this category were attributed to cloud cover over an irrigated corn field. This problem was corrected using the manual theme generation program.

Only 75 percent of the cereals category was correctly classified with the greatest number of incorrect classifications attributed to the unclassified pixels. Of the 1569 pixels left unclassified in this category, approximately 732 were attributed to cloud cover and the remainder were seen scattered throughout the rest of the check training areas as small blocks of unclassified pixels. As can be expected there was also confusion with the mixed grassland/scrub forest and grassland/pasture categories.

Approximately 63 percent of the 1585 pixels belonging to the exposed soils category were correctly classified. The largest number of incorrect pixels fell into the unclassified category and this problem could likely have been reduced by expanding the signature for exposed soils. All check training areas for this category were represented by at least a portion of the exposed soil pixels but in several instances many of the areas were underclassified. In one case, a large field reported as summerfallow was in fact represented by only 10 exposed soil pixels

and 146 grassland/pasture pixels. Positional error in the ground reference data or poor crop density were the likely source of error in this case as there was a large fallow field just to the north. In general, poor crop density due to the hot dry summer conditions could explain many of the fallow field classifications.

In the mixed woodland category 89 percent of the 8650 pixels were correctly classified. The greatest number of incorrectly classified pixels fell into the unclassified category. This error was associated with a thin strip of haze that was noticable over the north east portion of the image. The haze affected classification in the forested region along the Manitoba Escarpment. The problem was corrected using air photo mosaics at scale 1:15840 and the manual theme generation process.

In the potato category 88 percent of the 5734 pixels were correctly classified. The largest source of error for this category was due to 332 pixels of known potatoes being classified as corn. The problem again appeared to be border pixels of the potato fields being classified as corn. There were also 184 known potato pixels that were left unclassified. This error was likely attributed to a very tight spectral signature for potatoes.

In summary, approximately 74,235 pixels were checked and 64,436 pixels or 87 percent were correctly classified. A significant portion of the incorrect classifications (40 percent) were left unclassified; however, most of these errors were attributed to cloud cover and were corrected by manual methods. The remaining unclassified pixels were likely the result of purifying training areas to the point where some pixels actually belonging to the class were excluded. To offset this type of error the custerer or minimum area filter was applied. Also, as mentioned earlier, signatures for each class were purified so as to reduce overlap as seen in the scattergram. In doing so, one ran the risk of loosing some of the spectral signature for that class, but at the same time eliminated the chance of one cover type dominating another in the final classification. Thus by reducing overlap in spectral signatures, the opportunity to have unclassified pixels increased.

Total area measurements for each cover type are given in Table 2. It is worthwhile to note that 1.8 percent of the total area was left unclassified. Close examination of the classified results on the video display subsystem revealed numerous unclassified areas in the agriculturally developed area. These unclassified areas displayed shapes characteristics of field crops and in several instances ground reference data showed the presence of lentil crops in these unclassified areas. Several unclassified areas were the direct result of cloud or shadow covered areas and were corrected in the final mapped product using ground reference data and air photo mosaics.

TABLE 2

Percent cover and land areas by major cover type for the Assiniboine Delta Aquifer.

COVER TYPE	PERCENT	AREA (ha)
Rapeseed/Canola	3.6	9418.9
Corn	5.6	14549.8
Cereals	29.5	76137.9
Potatoes	2.0	5254.8
Exposed Soils	3.8	9842.2
Woodland/Conifer	0.1	175.3
Woodland/Mixed	23.9	61770.9
Mixed Grassland/Scrub	15.3	39243.8
Grassland/Pasture	14.2	36606.2
Water	0.2	517.9
Unclassified	1.8	4755.7
TOTAL	100	258273.4

4. CONCLUSIONS

The project has demonstrated that satellite data can be used to map land cover types at a level of detail that is sufficient for use in developing regional estimates of evapotranspiration. Digital image processing has enabled accurate area estimation of 10 land cover types on the Assiniboine Delta Aquifer. Factors contributing to the success of this application included good quality satellite and ground reference data, accurate cover type identification and generation of useful output products.

The importance of good quality satellite and ground reference data cannot be over emphasized in a project of this nature. Acquisition of ground reference data that corresponds in time and geographic position with satellite data is an absolute must in a detailed land cover study, particularly in an agricultural area. Crop rotation patterns and environmental conditions affecting crop development are two important reasons why correspondence in time is important. Correct identification of cover types in the field and knowledge of their exact geographic location are critical for interpreting satellite data and assessing the classification accuracy.

A comparison of manually generated check training areas with computer classified results for a sample of 74,235 pixels revealed that 64,436 pixels or 87 percent were correctly identified. The ability to accurately identify cover types varies with each individual cover type and is dependant not only on a cover type's spectral signature but also on the number of additional cover types included in the classification with similar spectral signatures. Two techniques used in combination proved to be successful in providing good discrimination between cover types with similar characteristics.

The first technique was the inclusion of a vegetation index (7-5)/(7+5), a ratio (5/7) and one principal component with the 4 MSS bands in the classification matrix. This provided the classification algorithm with additional information for discriminating between similar cover types. The second technique was the training area purification process which led to the development of "tighter" spectral signatures for each cover type and reduced the overlap between spectrally similar

cover types. Although these techniques will result in a greater number of pixels left unclassified, at least minimum areas for each cover type will be identified. Application of the minimum area filter can then be used to replace minimum areas and reduce the number of pixels left unclassified.

General soil conditions over the region should be considered when developing classification signatures and when evaluating classification results. Often a spectral signature for one cover type cannot always be applied to the same cover type located on the same landsat scene but in a different soil zone. In particular, the influence of soils and moisture on cover type development as well as the different reflectance characteristics of the various soil backgrounds was significant to the extent that a major discrepancy between cereals and mixed grassland/ shrub was evident on the Stocton Loamy Sands. A theme bit exchange routine developed specifically to resolve this problem over a large and complex region proved to be a successful technique for resolving this misclassification.

The technique used herein could not specifically identify irrigated areas. Application of the system to satelite data from different segments of the growing season could perhaps overcome this condition.

The degree to which remote sensing can be incorporated into the Water Resources Branch's surface water and groundwater programs could be reviewed in light of the need to acquire accurate, timely and relatively inexpensive regional land cover information. A detailed discussion of costs of this study are provided in Appendix II. Manitoba has large amounts of surface water and groundwater. The importance of this resource to the Province and to Canada will continue to grow as supplies of fresh water, relative to need, dwindle. Although the Water Resources Branch is involved in the management of many local projects (ie. relief wells, drainage schemes) it is the regional water aspects that are basically involved in long term planning and development. Management of water resources at the watershed, water district or aquifer system level is considered to be regional. Landsat derived information is best suited to regional applications and therefore can be considered by water managers and engineers as a tool for conducting regional hydrologic studies.

5. RECOMMENDATIONS

On the basis of this study, careful consideration should be given to these recommendations:

a) The Water Resources Branch and the Manitoba Remote Sensing Centre should continue to monitor land cover/land use on the Assiniboine Delta Aquifer with satellite data and develop a water usage index for each cover type that is consistant with local conditions and satellite derived information.

b) The Water Resources Branch and the Manitoba Remote Sensing Centre should explore multitemporal aspects of satellite monitoring. In particular, seasonal development of crops, extent of snow cover, snow accumulation and dissipation rates and changes in land cover/land use over time could be examined. As satellite technology develops these aspects will become much more readily definable.

c) The use of satellite data for monitoring land cover on other provincial aquifers or water sheds should be considered.

d) Use of satellite data should be considered with regard to analysis of other water related features such as soil, geomorphologic, and geologic conditions.

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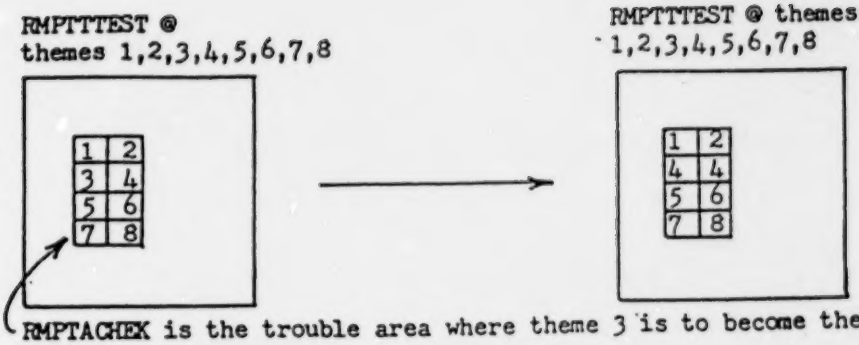
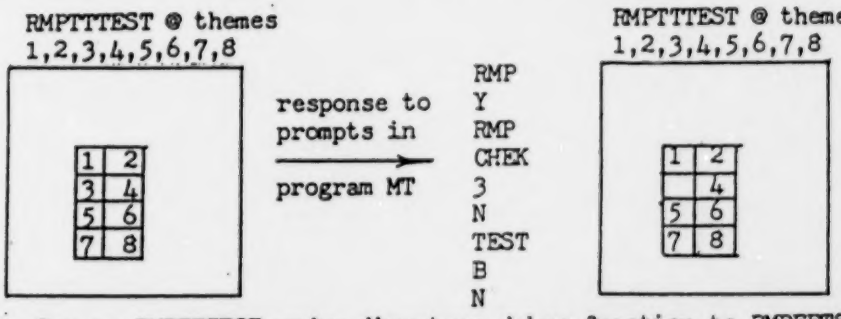
APPENDIX I

Theme Bit Exchange Routine



STEP 1 Create a BR tape containing the original theme file RMPTTTEST and the problem training area file RMPTACHEK.

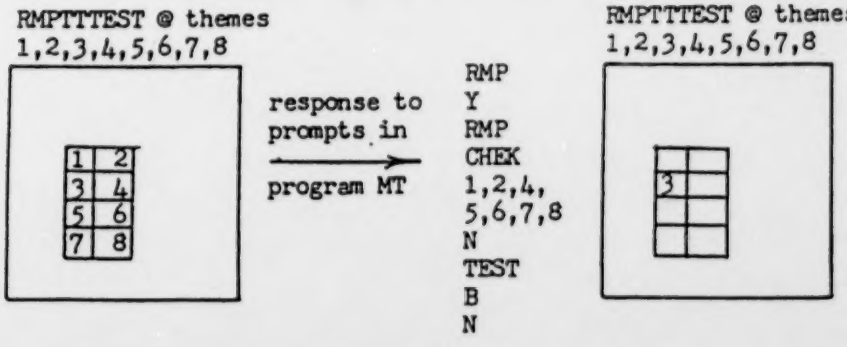
STEP 2 Use boundary mode in program MT to create a "hole" at theme bit position 3 in the problem training area RMPTACHEK.



STEP 3 Rename RMPTTTEST under directory debug function to RMPFFTST1.

STEP 4 Reload original theme file RMPTTTEST from BR tape.

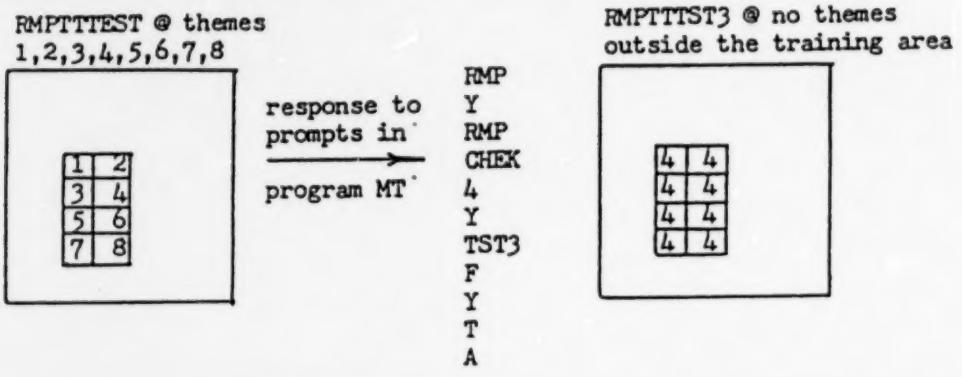
STEP 5 Use boundary mode in program MT to eliminate all but theme bit position 3 in the problem training area.



STEP 6 Rename RMPTTTEST to RMPFFTST2.

STEP 7 Reload the original theme file RMPTTTEST from the BR tape.

STEP 8 Use fill mode in MT to fill the problem training area with theme 4.



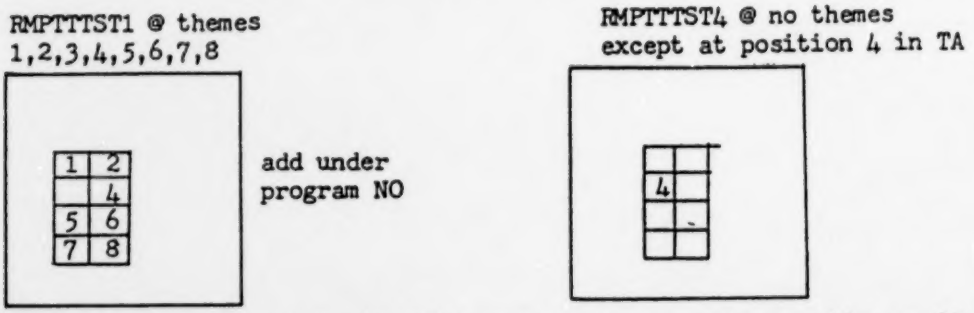
STEP 9 Rename RMPTTTST3 to RMPFFTST3.

STEP 10 Use the arithmetic combination of program NO to obtain an output image containing only pixels in theme bit position 4.

$$F_1(1.0) * F_2(0.25) = \text{RMPFFTST4}$$

where F_1 is the output product of step 6 with a scale factor of 1.0, and F_2 is the output product of step 9 with a scale factor of 0.25.

STEP 11 Use the addition subroutine of program NO to add the products of steps 2 and 10 to obtain the desired result.



STEP 12 Rename all FF files to TT files and display results on video monitor.

APPENDIX II

STAFF AND MATERIAL COSTS

COSTS

The material costs for the study were substantially below the original estimate; however, due primarily to the educational aspects, the manpower input was somewhat larger than anticipated. Table 1 shows a comparison between estimated, actual and projected costs of an operational program for the three major items required in a remote sensing project. A more detailed breakdown of these items was given in the original project proposal of March 1983.

In perusing this cost comparison it is important to remember two facts. First, the original estimate was prepared with limited experience on use and application of the ARIES-II image analysis system. Second, the actual amount reflects high educational costs. These would not be part of an operational program. With these two points in mind, the following is a discussion of differences between original and actual amounts for each major item.

The amount spent on materials for the project was $1,485.00 less than the original estimate for two primary reasons. First, data acquisition costs (ie. CCT prices) used in the original estimate were not put in place because of the Canadian Government's 6 and 5 restraint program. Second, at the time the original estimate was made there was no known pricing arrangement in effect for producing the applicon plots. Original estimates were therefore inflated to reflect this uncertainty. As a result the actual amount was considerably less than estimated.

In an operational program material costs would be lower because fewer CCT's would be purchased. Costs could be further reduced by data sharing between users with different projects in the same geographical area. Output product costs would remain unchanged. A further cost variance factor is that estimates for the operational program were based on 1983/84 prices.

The actual amount of staff time required to complete the project was 13 staff-person days less than originally estimated. The Water Resources Branch contributed 13 extra staff-person days and the combined total for MRSC and CCRS was 16 staff-person days short of the estimate. The original estimate for Water Resources staff time was considered to be a level of committment that would ensure the results of the study would satisfy the Branch's technical requirements. The actual amount of time reflects

TABLE 1: SUMMARY AND COST COMPARISON BETWEEN THE ORIGINAL PROJECT ESTIMATE, THE AMOUNT ACTUALLY USED AND A PROJECTED OPERATIONAL PROGRAM ESTIMATE.

ITEM (units)	[1] ORIGINAL ESTIMATE	ACTUAL AMOUNT	[4] OPERATIONAL PROGRAM
I MATERIALS ($)			
Data Acquisition	2,915	2,500	1,000
Output Products	2,145	1,075	1,000
TOTAL	5,060	3,575	2,000
II STAFF (person-days)			
MRSC & CCRS	96	70	55
Water Resources	22	[3] 35	21
TOTAL	118	105	76
III [2] COMPUTER TIME (hours)	150	270	150

FOOTNOTES

1. Original estimate included a 10% contingency factor.
2. The original estimate for computer time was given as $7500 based on $50.00 per hour for 150 hours.
3. The actual amount shown here is based on known participation in image analysis and report writing and also includes an estimate for collection of ground reference data.
4. An operation program is defined as one that includes the same geographic area and has the same objectives as the original project.

their committment to better understand the technology. Under an operational program the total staff time would be significantly reduced because of the experience gained during the previous project.

The actual amount of computer time used for this project exceeded the original estimate of 120 hours. This time increase can be accounted for because of the trial and error learning processes, training and deomonstration components and development of the special theme bit exchange routine. In an operational program these factors would be minimal. Therefore the amount of computer time would be near the original estimate of 150 hours.